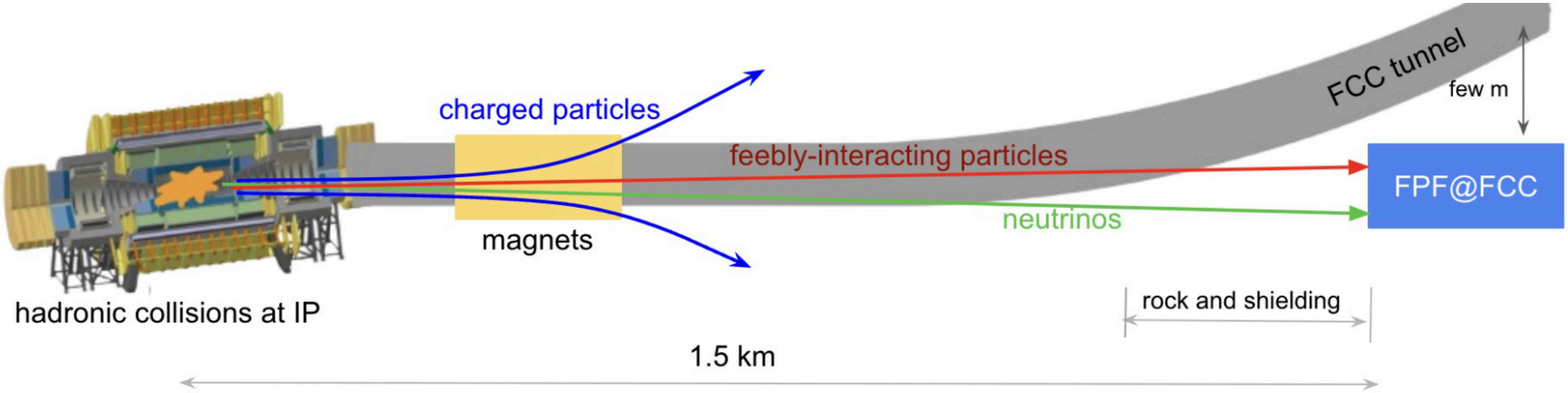
FPF@FCC: a Forward Physics Facility integrated with the FCC-hh

Juan Rojo, VU Amsterdam & Nikhef



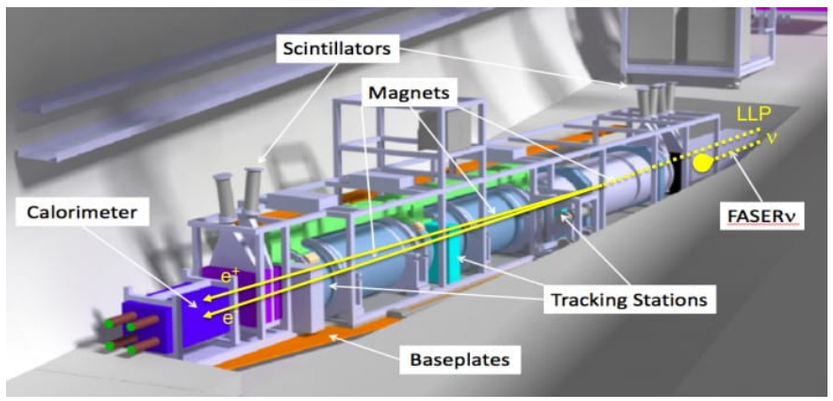
based on Roshan Mammen Abraham, Jyotismita Adhikary, Jonathan Feng, Max Fieg, Felix Kling, Jinmian Li, Junle Pei, Tanjona Rabemananjara, **JR**, and Sebastian Trojanowski**, to be submitted this week**

FCC-hh Studies for the next European Strategy: Kickoff Workshop

CERN, 3rd September 2024

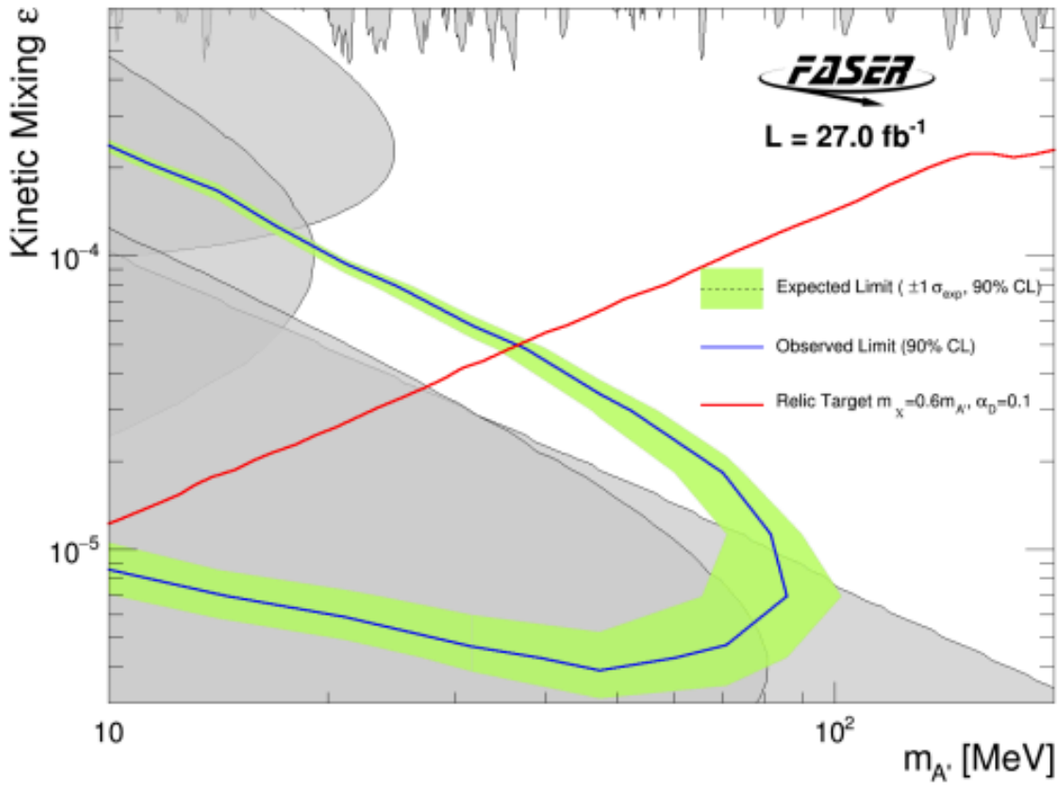
Far-Forward Experiments at the LHC

FASER & FASERν

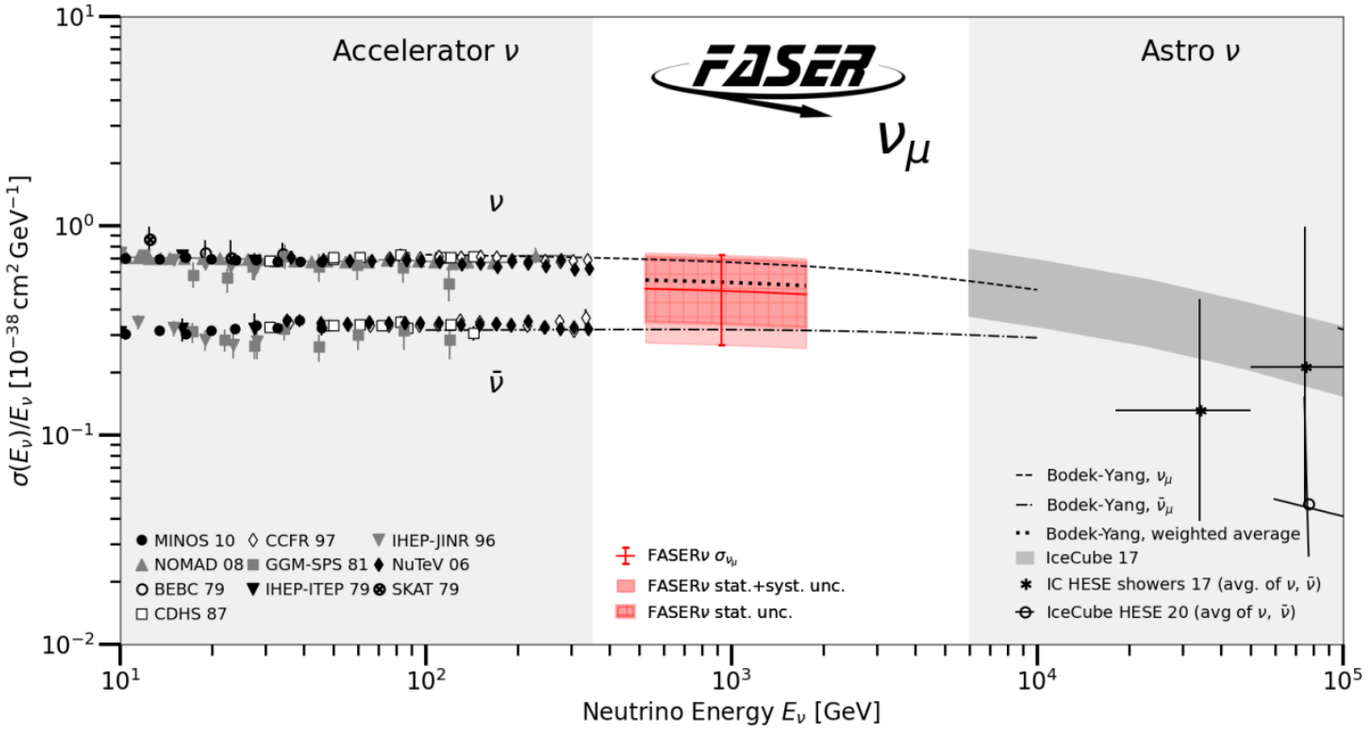


SND@LHC

Dark Photon searches

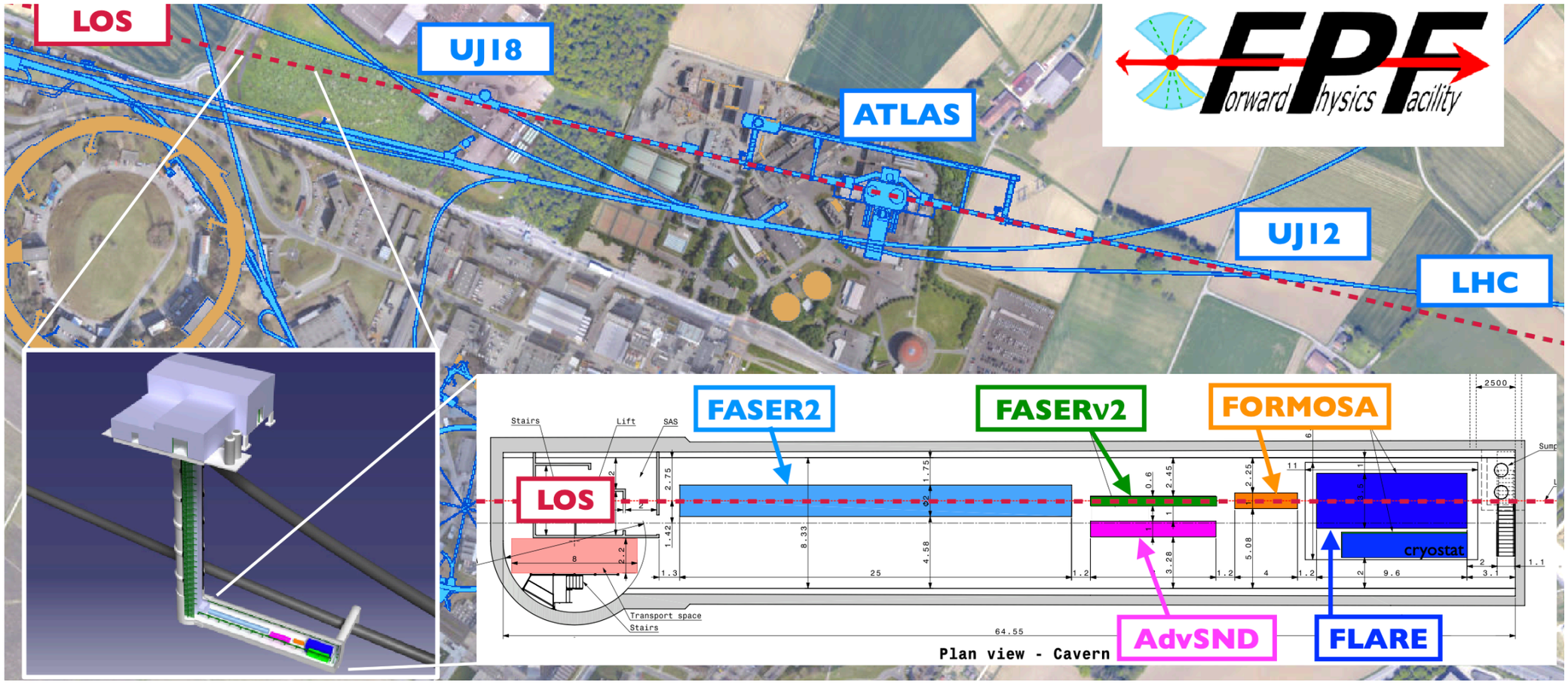


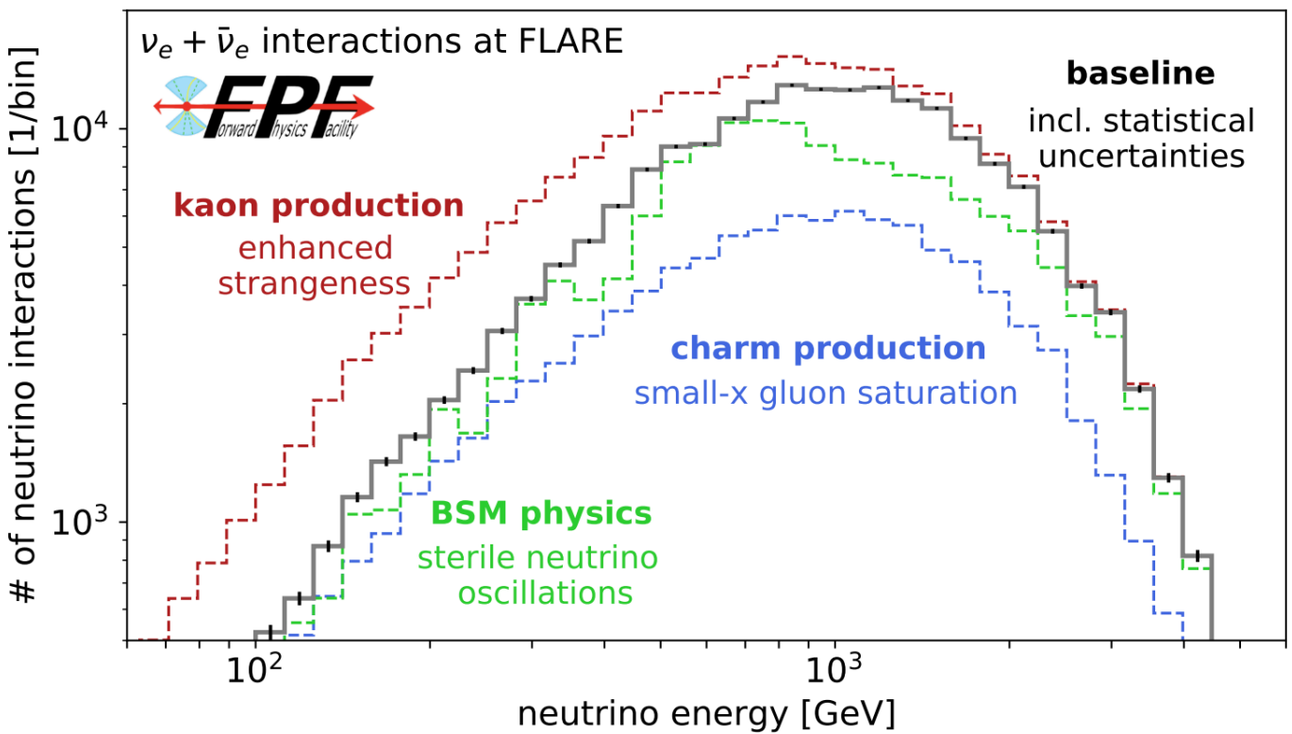
Neutrino cross-sections at TeV energies



Far-Forward Experiments at the HL-LHC

Forward Physics Facility

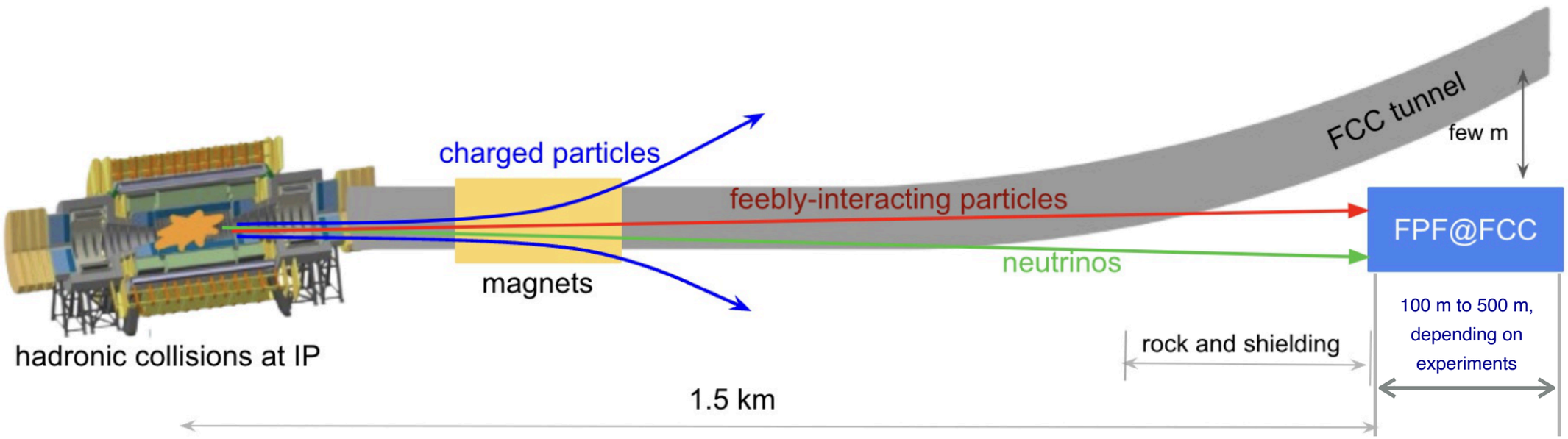


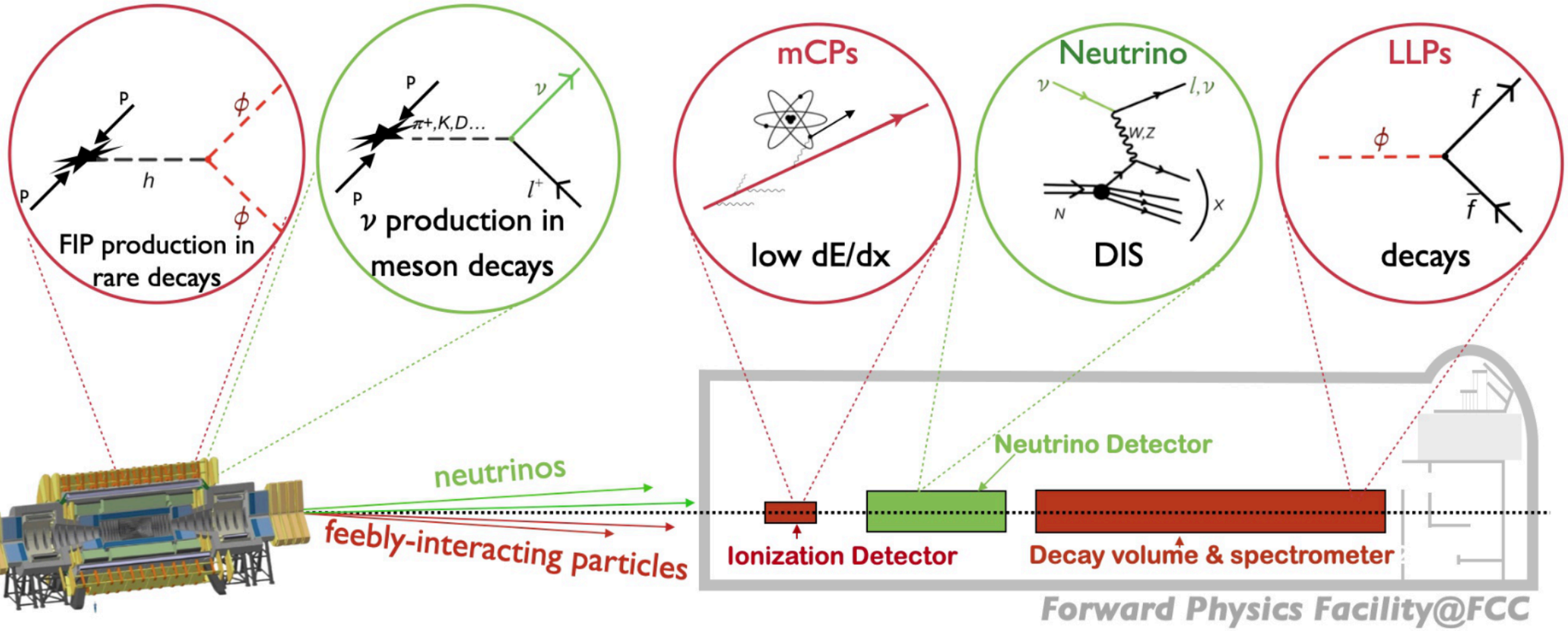


- Rich, diverse program from **BSM** and **neutrino physics** to **QCD** and **astroparticle physics**
- Pin down proton and nuclear PDFs, access forward light hadron and charm production, constrain the prompt neutrino flux, ….
- Access to **BSM signatures** relevant to swathes of models not covered by the LHC detectors.

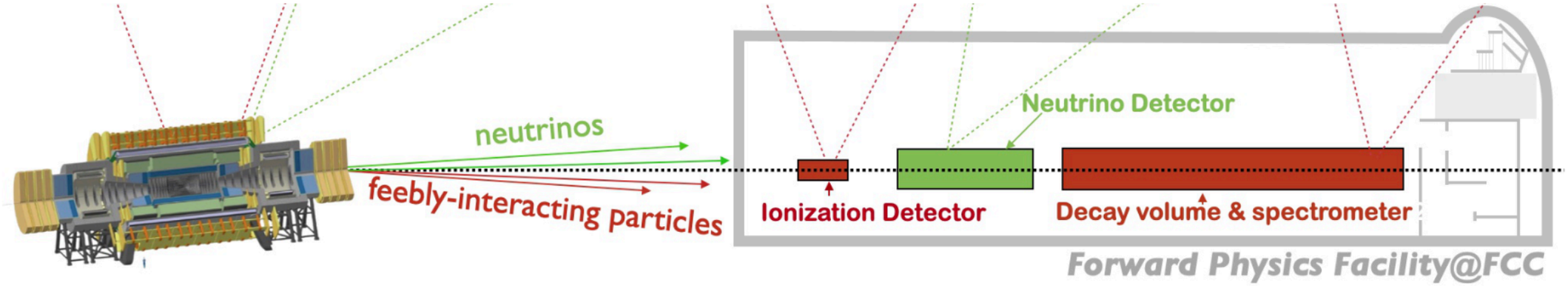
FPF@FCC

Facility to **detect neutrinos and BSM particles** produced at the FCC-hh in the **forward direction**





Detectors



Neutrino detectors

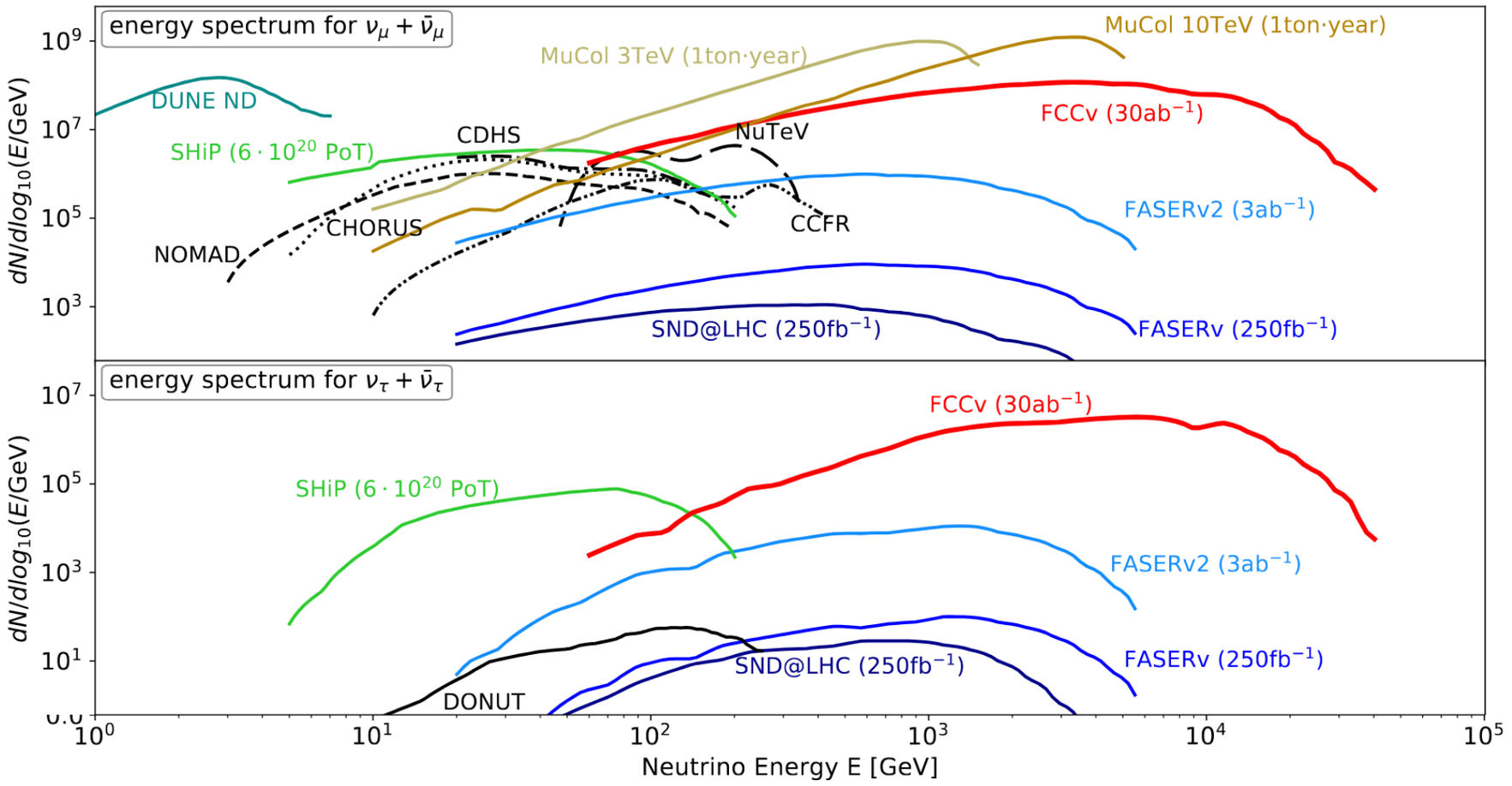
Detector	Geometry	Rapidity	$\mathcal{L}_{\rm pp}$	$\sqrt{s}$	Acceptance
FASERν	20 cm × 25 cm × 80 cm	$\eta_\nu \geq 8.5$	250 fb^{-1}	13.6 TeV	$E_\ell, E_h \gtrsim 100$ GeV, $\theta_\ell \lesssim 0.025$
FASERν2	40 cm × 40 cm × 6.6 m	$\eta_\nu \geq 8.4$	3 ab^{-1}	14 TeV	$E_\ell, E_h \gtrsim 100$ GeV, $\theta_\ell \lesssim 0.05$
FCCν	40 cm × 40 cm × 6.6 m	$\eta_\nu \geq 9.2$	30 ab^{-1}	100 TeV	$E_\ell, E_h \gtrsim 100$ GeV, $\theta_\ell \lesssim 0.05$
FCCν(d)	40 cm × 40 cm × 66 m	$\eta_\nu \geq 9.2$	30 ab^{-1}	100 TeV	$E_\ell, E_h \gtrsim 100$ GeV, $\theta_\ell \lesssim 0.05$
FCCν(w)	1.25 m × 1.25 m × 6.6 m	$\eta_\nu \geq 8.1$	30 ab^{-1}	100 TeV	$E_\ell, E_h \gtrsim 100$ GeV, $\theta_\ell \lesssim 0.05$

Decay volume & spectrometer (targeting BSM)

Detector	Geometry	$\mathcal{L}_{\rm pp}$	$\sqrt{s}$	Acceptance
FASER	$\pi(10\text{ cm})^2 \times 1.5$ m	150 fb^{-1}	14 TeV	$E_{\rm vis} \gtrsim 100$ GeV
FASER2	$\pi(1\text{ m})^2 \times 5$ m	3 ab^{-1}	14 TeV	$E_{\rm vis} \gtrsim 100$ GeV
FCC-LLP1	5 m × 5 m × 50 m	30 ab^{-1}	100 TeV	$E_{\rm vis} \gtrsim 100$ GeV
FCC-LLP2	20 m × 20 m × 400 m	30 ab^{-1}	100 TeV	$E_{\rm vis} \gtrsim 100$ GeV

- Ambitious detector concepts, **technology-agnostic**
- For neutrino physics take **FASER ν2 as baseline**
- Consider also a **polarised detector** for neutrino DIS
- Costing of FPF@LHC is **O(CHF50M) for facility + O(CHF30M) for experiments**

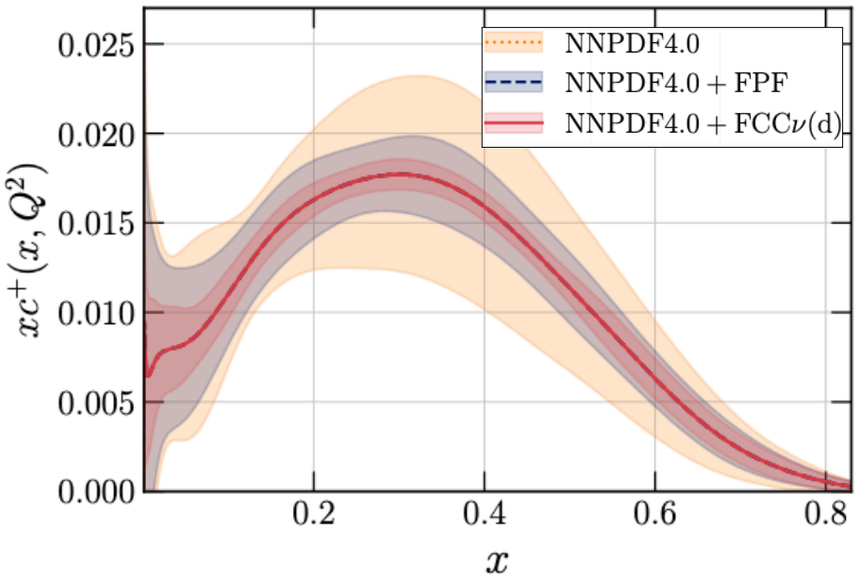
Neutrino Fluxes

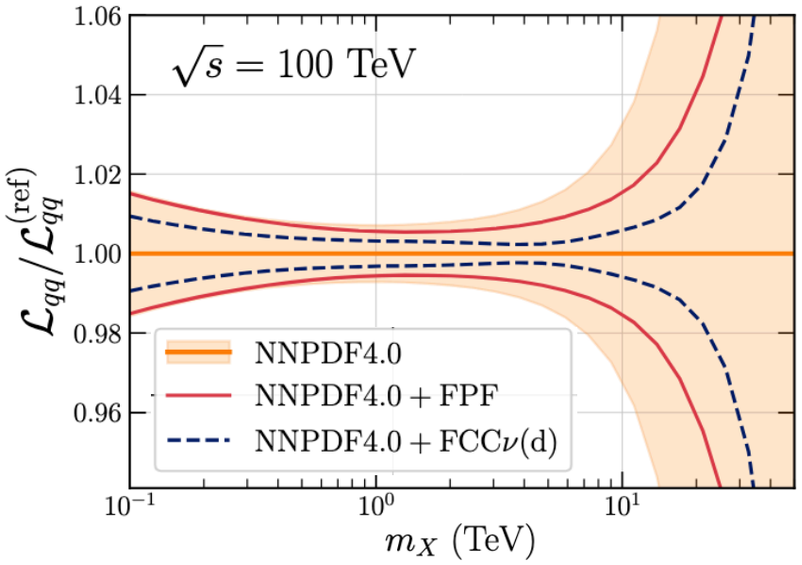


Detector	$N_{\nu_e} + N_{\bar{\nu}_e}$	$N_{\nu_\mu} + N_{\bar{\nu}_\mu}$	$N_{\nu_\tau} + N_{\bar{\nu}_\tau}$
FASERν	2.1k	11k	36
FASERν2	220k	1.1M	4.3k
FCCν	62M	130M	3.2M
FCCν(d)	620M	1.3B	32M
FCCν(w)	170M	370M	11M

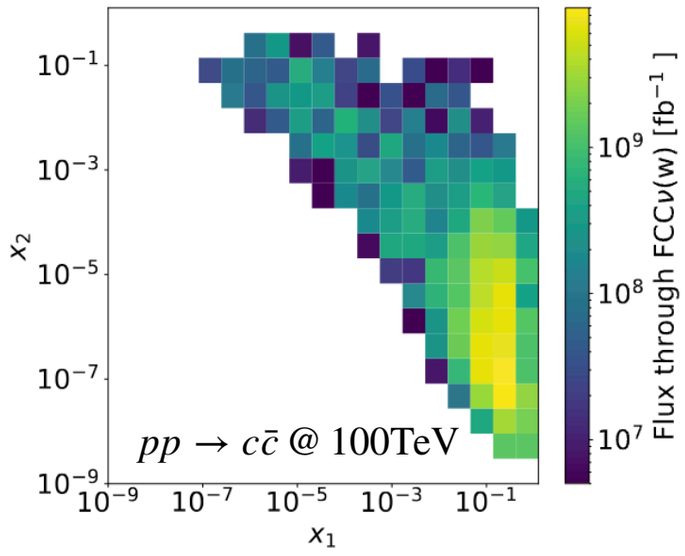
- Enormous neutrino fluxes with energies **reaching 40 TeV**
- Up to **10^9 electron & muon neutrinos**, **10^4 tau neutrinos**
- Sizeable event samples also for **neutrinos from p+Pb collisions**
- Extend FCC-hh physics program with a rich portfolio of **neutrino science**
- Most energetic neutrinos that would be ever produced in lab experiments, **overlap with cosmic neutrinos**

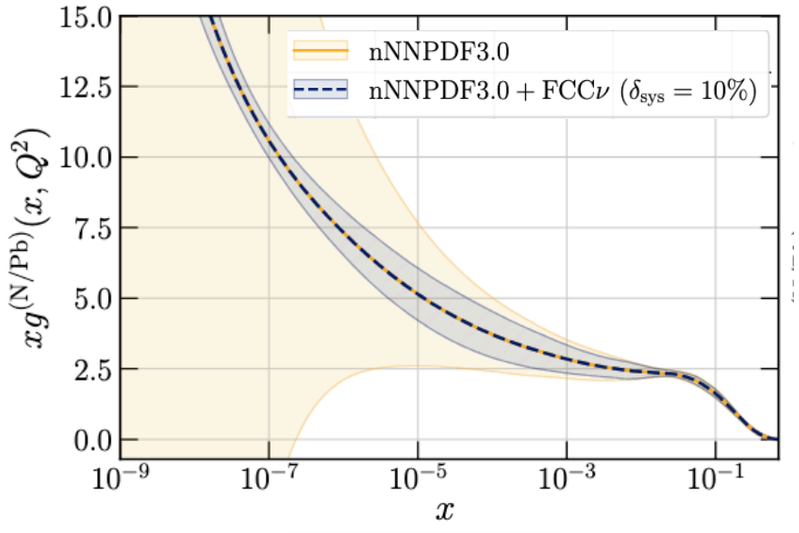
QCD studies



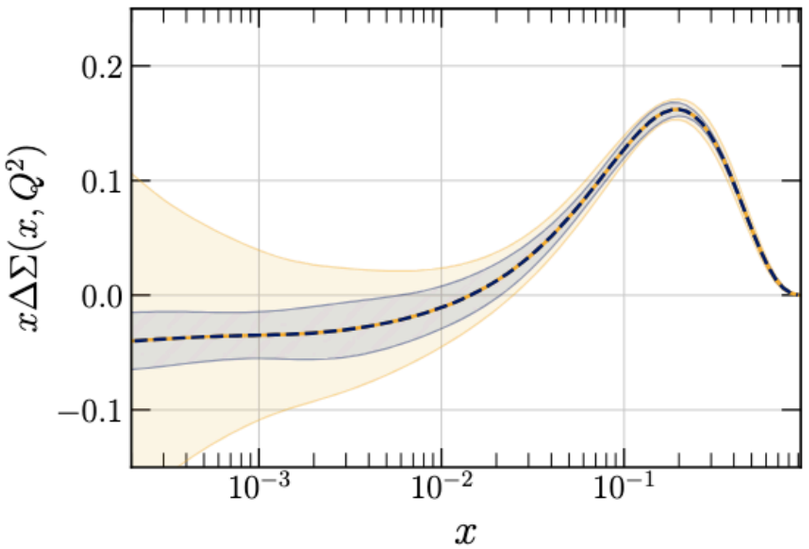


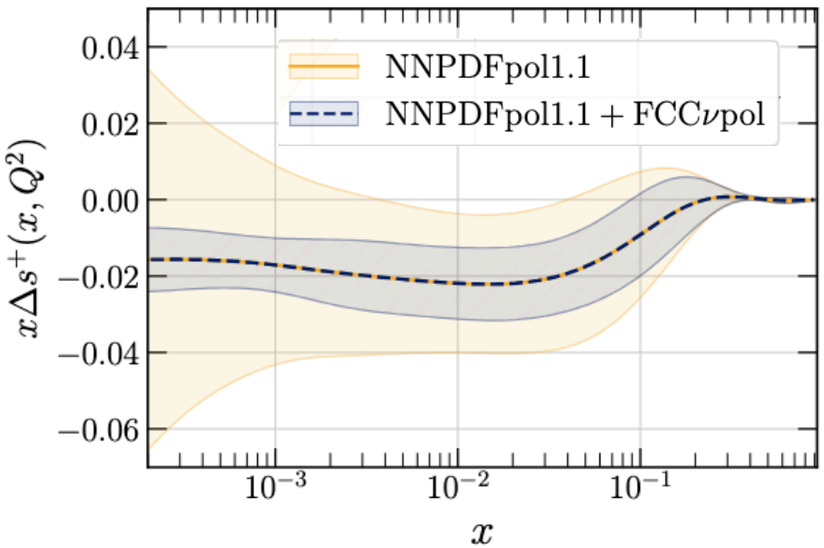
- Neutrino DIS with **< 0.1% statistical uncertainties**
- Stringent constraints in large-x PDFs, relevant for **searches in the $m_X > 10$ TeV region**





- Constrain **nuclear PDFs down to $x \sim 10^{-9}$** via $\mathrm{p} + \mathrm{Pb} \to c + \bar{c} + X$
- Up to **10^5 events for charm production** (in hard scattering) in p+Pb at $\sqrt{s_{\mathrm{NN}}} = 63$ TeV

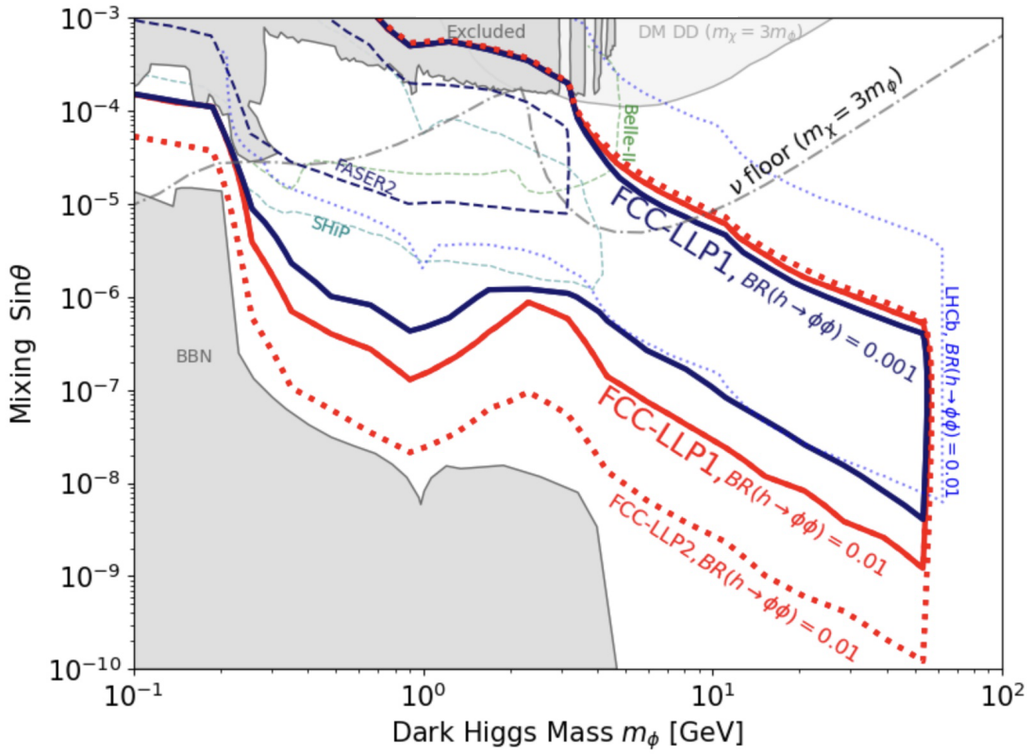


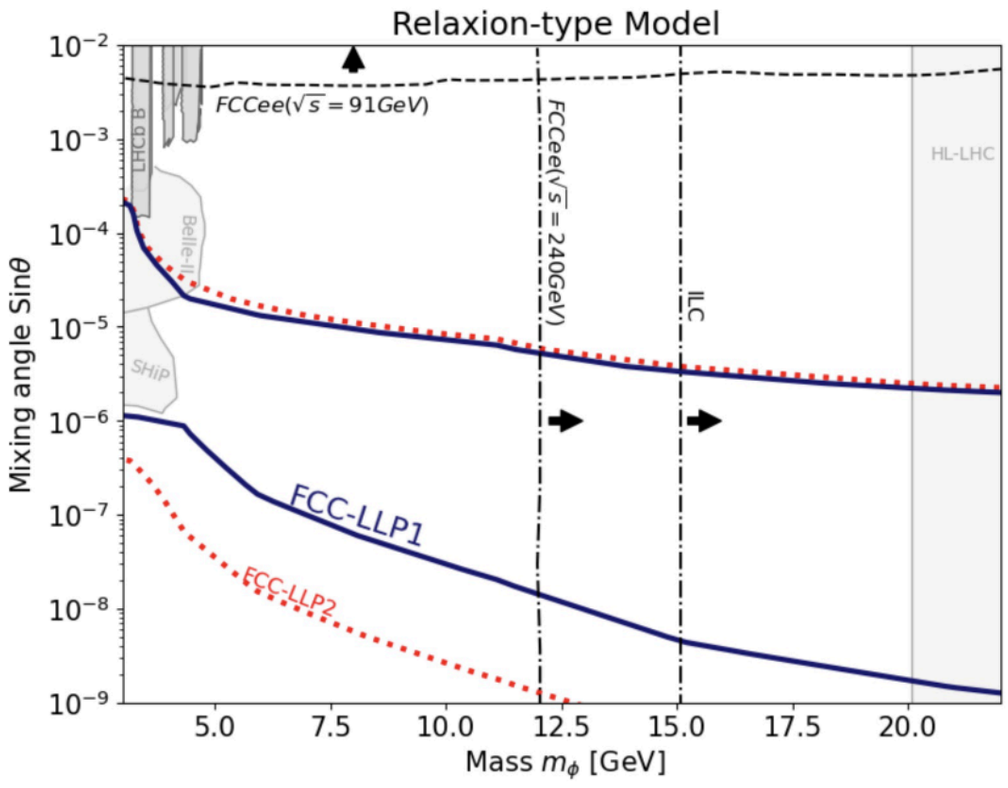


- First-ever neutrino DIS on polarised targets: pin down **proton spin decomposition**
- Up to **10^6 events** for COMPASS-like detector with FASERν2 geometry

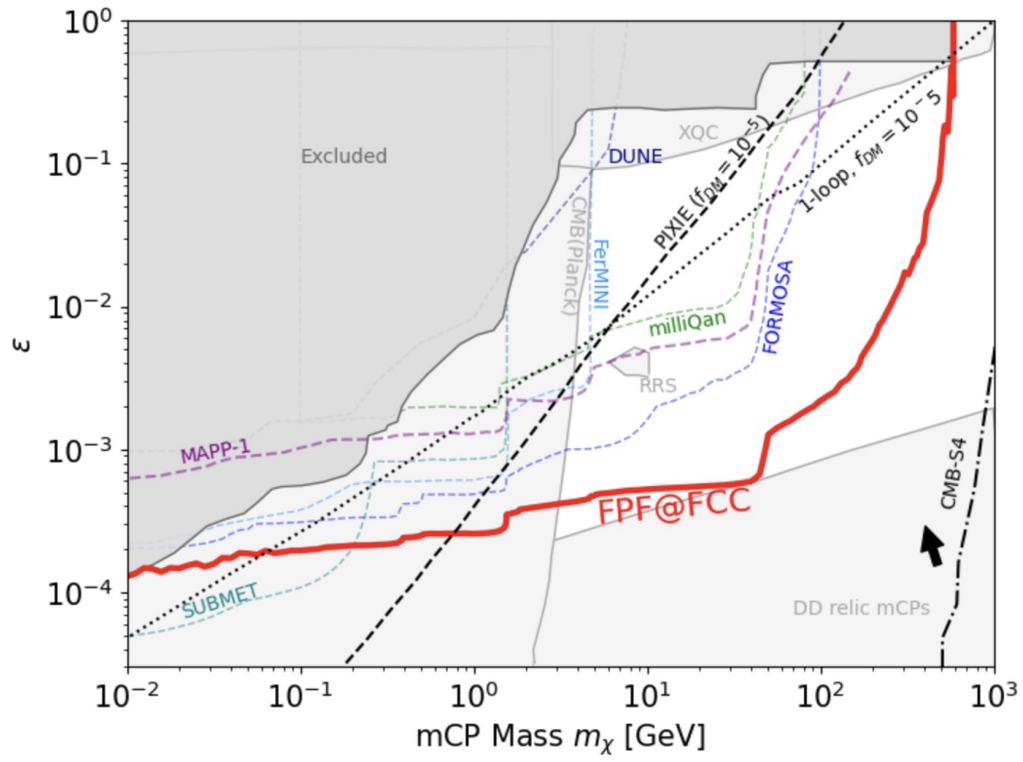
BSM physics sensitivity

Long-Lived Particles Searches





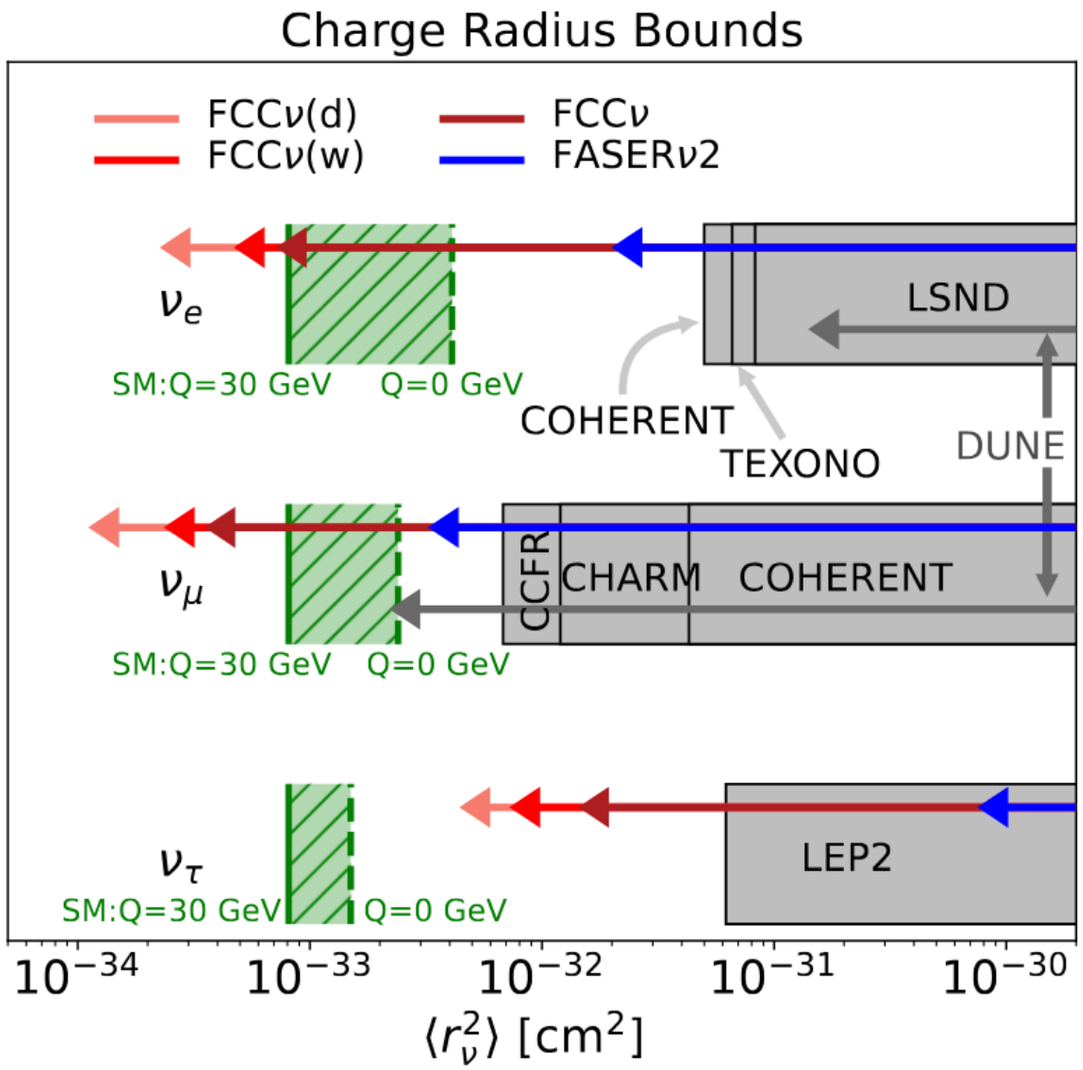
Millicharged Particles

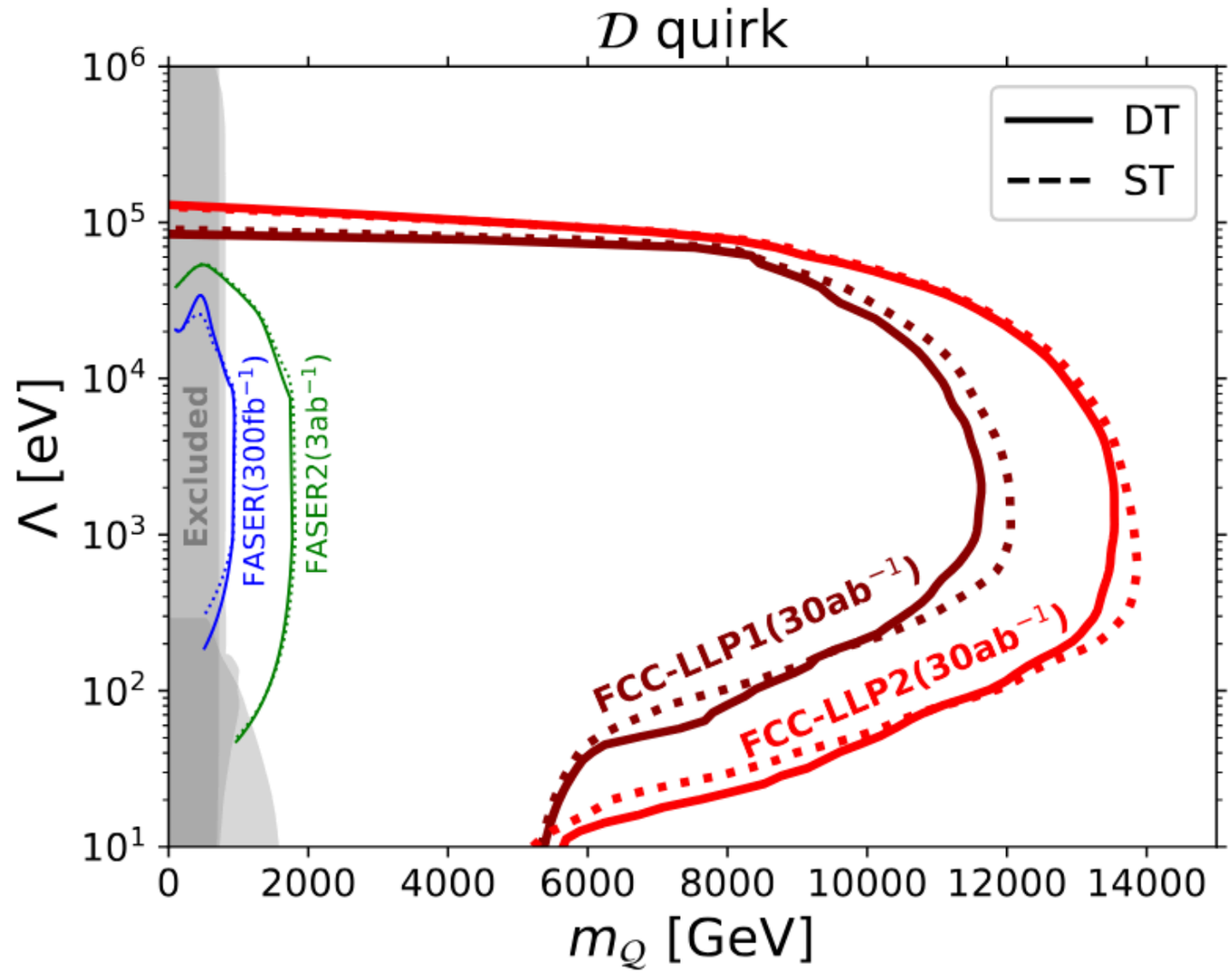


- **Dark Higgs bosons** produced from h→ϕϕ, thanks to enormous forward rate at 100 TeV
- Test **scalar portal to dark matter** far below the neutrino floor
- **Relaxion-type LLPs** sensitivity in low-mass region beyond reach of FCC-ee
- Close the gap **between accelerator and direct detection searches** for millicharged dark matter

WIP: collect FCC-ee sensitivity on LLPs

BSM physics sensitivity





Measure for the first time **neutrino charge radius** and its flavour dependence

sterile neutrino oscillations, neutrino-philic new particles, neutrino **non-standard interactions**, …

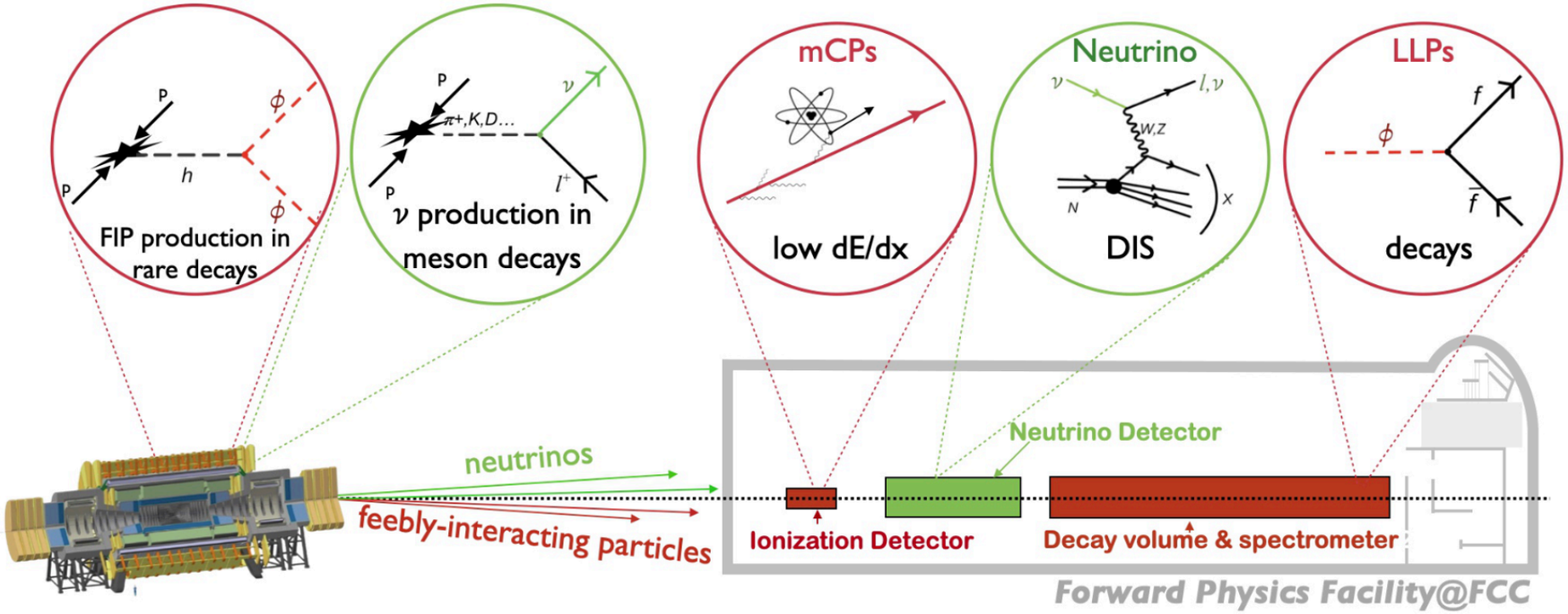
Quirks: dark-sector particles charged under dark QCD, motivated by **neutral naturalness**

Discover Quirks **up to ~14 TeV** for a wide range of (dark) confinement scales Λ

Summary and outlook

- First assessment of FPF@FCC demonstrating its reach for **QCD physics, neutrino properties, and BSM sensitivity** (e.g. discovering LLPs up to $m \sim 50$ GeV GeV, quirks up to $m \sim 10$ TeV
- Could be built with **minimal interference** with the FCC-hh construction and operation
- Technology-agnostic study, but several successful detector realisations available

An FPF-like suite of experiments **integrated in the FCC-hh** offers unique, cost-effective physics opportunities that markedly extend its science portfolio



Additional motivation to **realise the FPF at the HL-LHC** as an **essential precedent** to optimise forward physics experiments enabling the FCC to fully achieve its physics potential